Measurements of Circuit Board Induced Noise into Parallel Mounted PIN Diode

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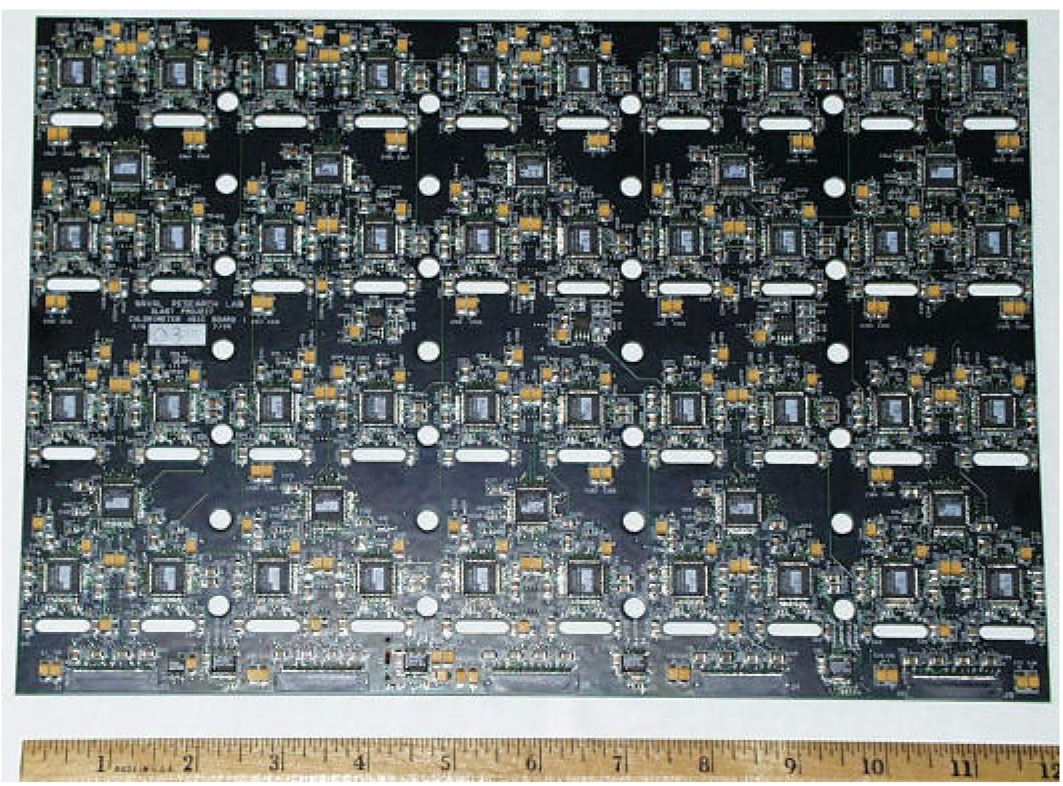
SUMMARY:
This paper documents measurements of circuit board signal coupling to a parallel mounted PIN photodiode. This physical arrangement between the circuit board and detector diode was used on the GLAST prototype calorimeter and will also be used on the flight calorimeter circuits. The measurements show that a grounded foil patch on the diode housings is not nearly as effective in reducing noise pickup as a large grounded metallic sheet between the circuit board and diodes.

SETUP:
A spare prototype calorimeter circuit board (Figure 1) was used with a spare PIN photodiode. The calorimeter board is one which uses the Maxim MAX189 Analog to Digital Converters (ADCs). The circuit board contains 40 front-end Application Specific Integrated Circuits (ASICS) with one ADC per ASIC. The ASIC chips are mounted on top of the board; the ADC chips are mounted under the board. The diode area is 1 square cm and it is reversed biased with 40 volts. Measurements were taken with a 10X scope probe using a ground spring clip (detail Figure 4), minimizing the probe ground loop path. The measurements were taken from the shaper output of the Low Energy x4 channel of a single front end CSICAL ASIC.

Figure 1. Calorimeter circuit board containing frond-end ASICs. PIN diodes mounted underneath, leads feed through oval holes.

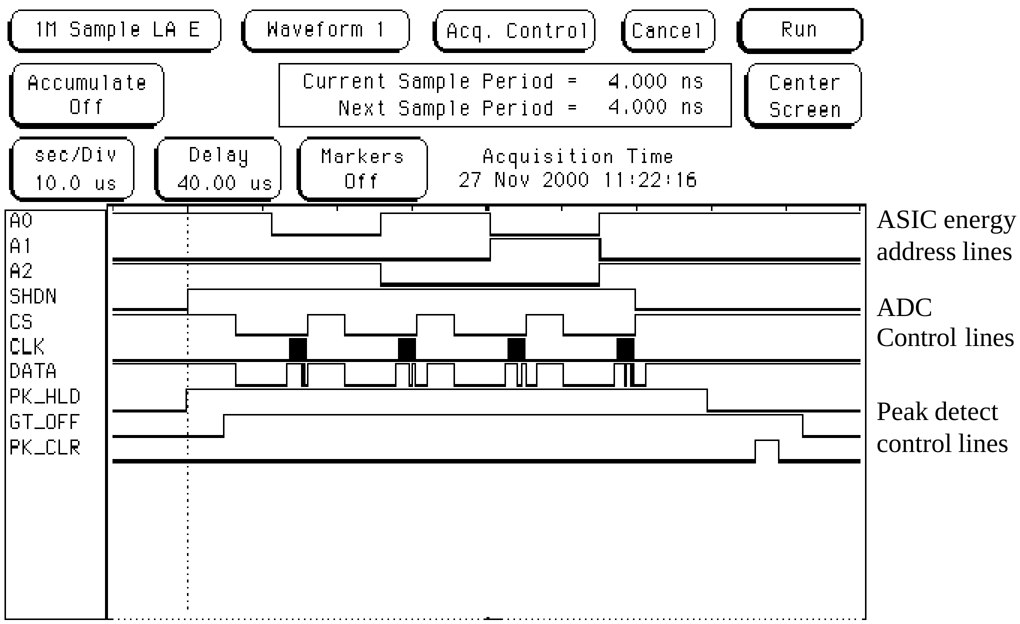


The digital signals on the circuit board that can couple to the pin diode are:

1) ASIC energy address lines, quantity three, which switched between 0 and +5V during the 4-channel readout. These lines are routed under the ASIC (detail Figure 3), and generally over the PIN diode. The signals address which of the four ranges are output to the ADC. The address signals are referenced A0, A1 and A2.

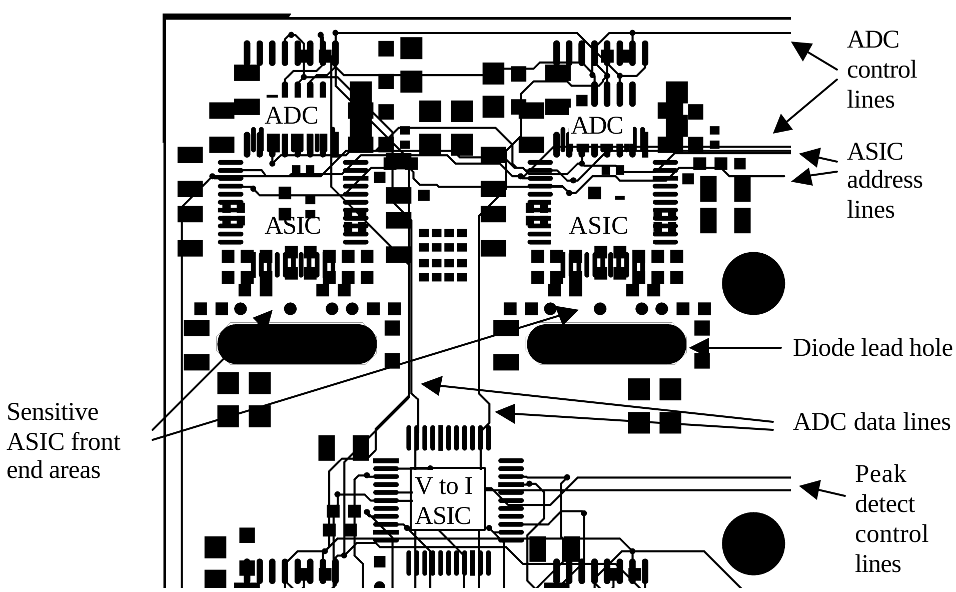
2) ADC readout control lines, quantity three, which switch between 0 and +5V. Figure 2 shows the timing relation between the ASIC address control lines and the ADC readout lines. On the circuit board these digital control lines route around the ASIC and generally around the PIN diode (detail Figure 3). The ADC signals are referenced as SHDN (shutdown), CS (chip select) and CLK (clock).
3) Peak detect control lines, quantity three. These signals run on the board as 0 to +5V lines, and are converted in a V to I ASIC (Figure 3) and applied to the front end ASIC as 0.9V to 1.1V signals. The peak control lines are referenced PK_HLD (peak hold), GT_OFF (gate off) and PK_CLR (peak clear).

Figure 2. Timing relationship of the digital switching waveforms on calorimeter board. 4 range readout mode.



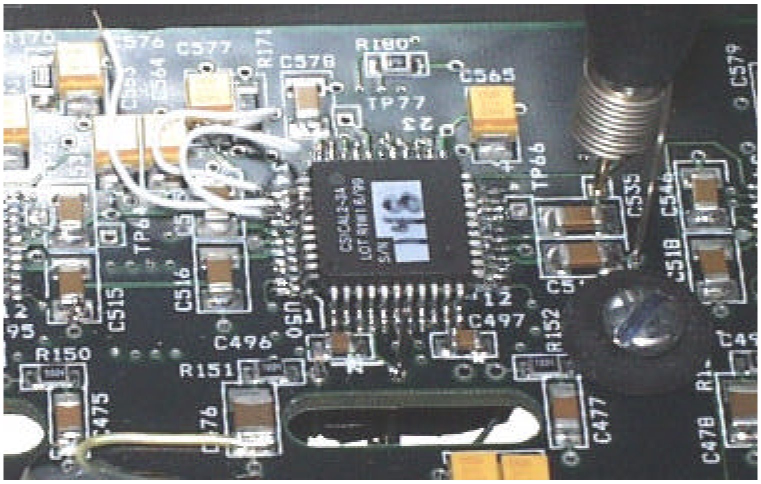
All of these signals route internally in the PCB between the power and ground planes, except when making physical chip connections.

Figure 3. Detail of digital signals routed on calorimeter circuit board. Component footprints shown for both top and bottom of board.



When switching, the ASIC address lines couple to the ASIC front-end amplifier through the package leads. In order to perform measurements without this inherent noise, the address pins of the ASIC output being examined were lifted and hard wired to fix the address at Low Energy x4 (detail Figure 4). In this manner, the coupling of the address lines to the ASIC front end could be investigated without the package-coupling component.

Figure 4. Detail of 3 ASIC address pins hard wired. Also note scope probe with coiled ground spring attachment to the right.

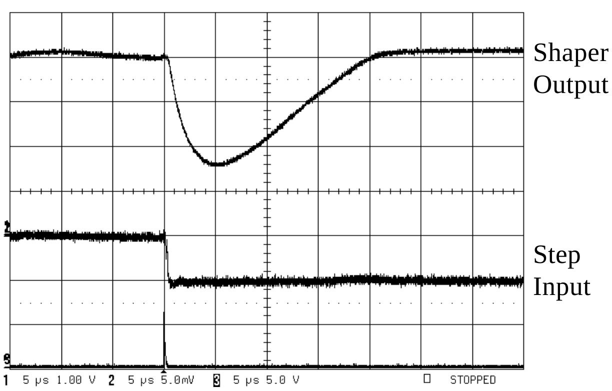


Baseline:

Calibrating the shaper output with respect to amplifier input:

The ASIC was set to the same gain and shaping parameters that had been used for previous accelerator beam tests. Figure 5 shows the front-end gain and shaping time from a 5.0mV step signal though 10pf capacitor. Injected charge is 0.005V * 10E-12F = 50fC. The peak output voltage is about 2.2V. The gain is thus 44mV/fC, or using the conversion 1electron charge (e-) is 1.6 E-19 Coulomb, gain is 21mV/3000 e- where 3000 electrons is the expected signal level per MeV.

Figure 5. Front-end Gain Measurement.



Noise Without Diode attached:

Noise pickup without a detector diode attached to the front end is examined first. Any noise seen is then due to the circuit board itself. Figure 6 below shows noise present when the ADCs are not run during a readout cycle, Figure 7 when the ADCs are run. When the ADCs are not running, the only switching activity on the board is from the peak-detect circuit control lines, which create a small amount of noise. With the ADCs running, the noise seen at the middle of the address periods is due to the sampled signal being released at the end of a conversion. The ADC noise seen is not due to the individual ADC connected to the probed ASIC. Neither disconnecting the individual ADC power pin from the supply nor disconnecting the ASIC output to the ADC input resulted in any change to the front-end noise (data not shown).

Figure 6. Front End Shaper Noise, No ADCs.

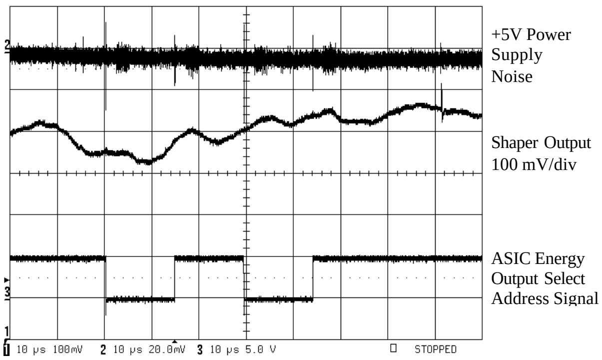
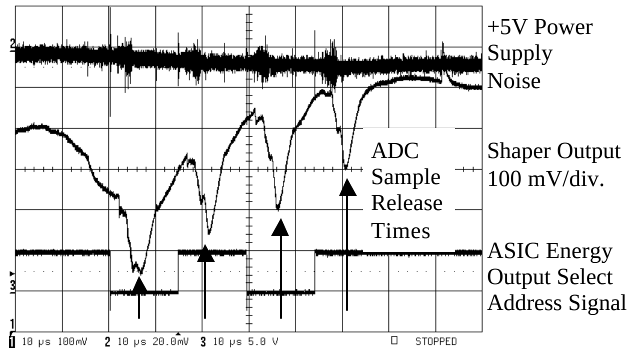


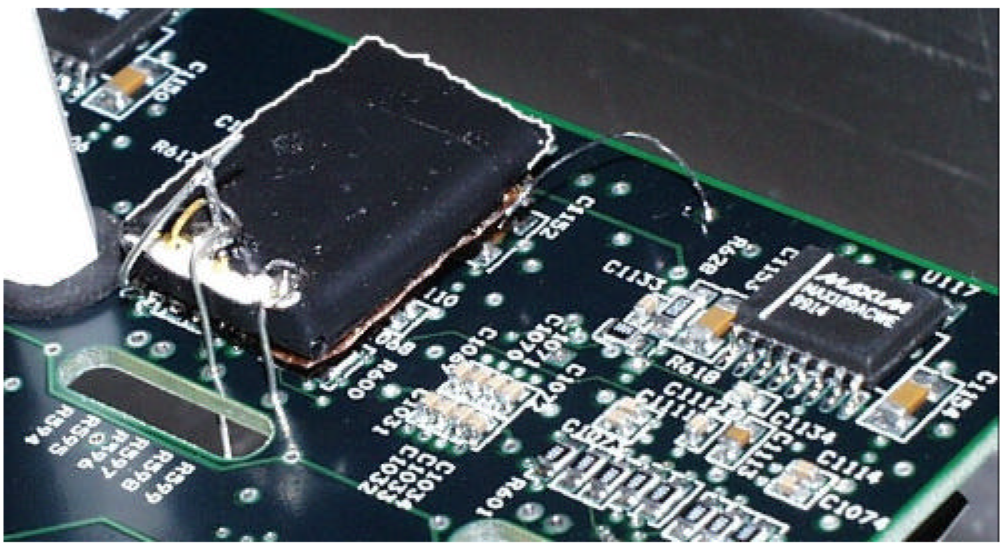
Figure 7. Front-end Noise with All ADCs Running.



Noise With Diode Attached:

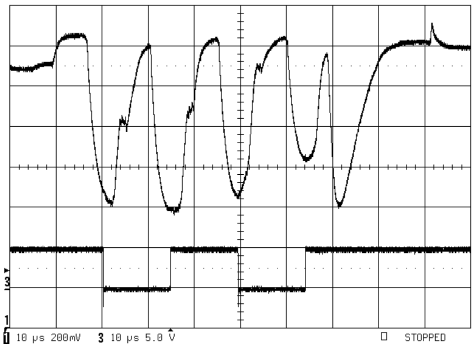
The PIN diode was wrapped in black electrical tape and mounted 5 mm underneath the circuit board.

Figure 8. Detail photo of black wrapped PIN diode 5mm from circuit board bottom, copper plate under diode. White line drawn around part of diode for visibility. Note diode is partially over a MAXIM ADC, as shown to the right.



The scope plot below in Figure 9 show that the shaper output noise has increased with the addition of the PIN diode connected to the front end. The diode is reversed biased at 40 volts to minimize its capacitance. Putting ungrounded copper between the circuit board and the diode increases the noise coupling by a factor of about 2.5, as shown in Figure 10.

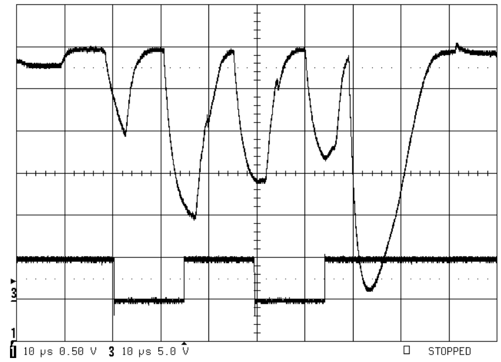
Figure 9. Noise Pickup with PIN Diode.



Shaper Output 200 mV/div.

ASIC Energy Output Select Address

Figure 10. Un-Grounded Foil on Diode.



Shaper Output 500 mV/div.

ASIC Energy Output Select Address

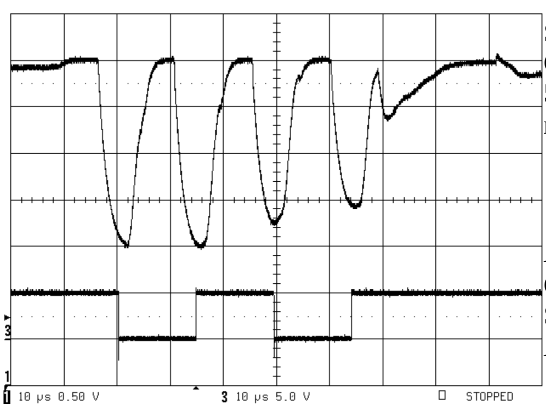
Test of Shielding the Diode:
Three methods of shielding the diode were examined. The methods are:

1) Grounded copper foil patch on diode.
2) Grounded Mu metal patch on diode.
3) Grounded foil plane between circuit board and diode.

Mu Metal is a nickel based ferromagnetic material used for shielding magnetic fields.

The following measurements were made with the circuit board outside of a metal box, 100 mm above a lab bench static mat. The PIN diode was mounted 5 mm below the PCB, as close as possible to the bottom-side components. Two sizes of shielding patches were tested: a small one the size of the diode, the other a large sheet the size of the circuit board. Results of the different shielding experiments are shown in Figure 11 to Figure 14.

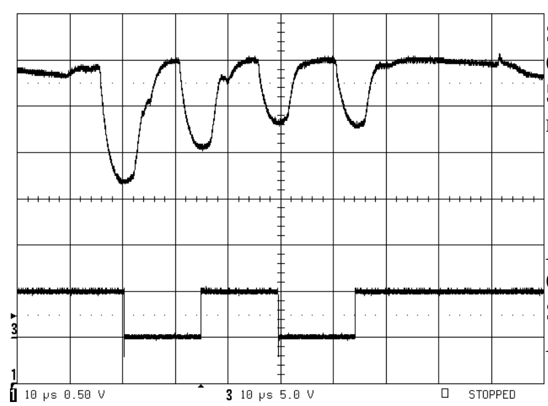
Figure 11. Unshielded diode.



Shaper Output 500 mV/div

ASIC Output Select Address

Figure 12. Shield with grounded copper patch.



Shaper Output 500 mV/div

ASIC Output Select Address

Figure 13. Shield with grounded Mu metal patch.

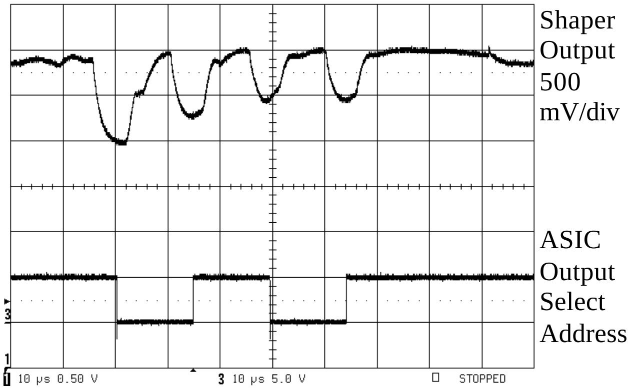
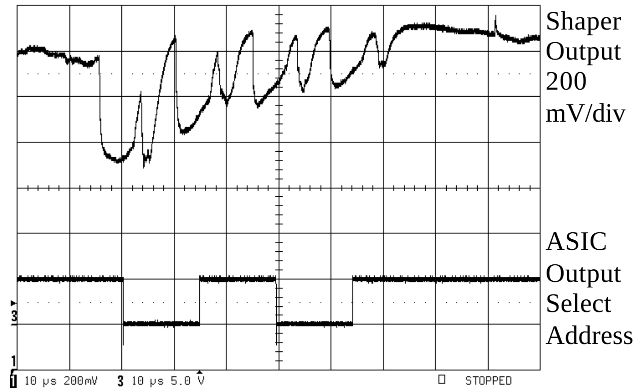


Figure 14. Shield with large grounded aluminum foil sheet.



From the above plots, neither the copper nor Mu metal patches on the diode significantly reduced the pickup noise. The grounded aluminum sheet however reduced the pickup noise by about a factor of 4. In Figure 14, the address switching noise is attenuated to the level of the ADC readout noise. A foil patch in addition to the large sheet was not tried due to the close proximity, both items would be touching.

<u>Pickup Noise vs. Distance:</u>
Pickup noise as a function of diode distance was examined, with results shown in Figure 15 and Figure 16. In extending the length of the diode leads, larger amounts of switching noise were picked up both for parallel run diode leads and twisted pair leads. Only a coaxial cable lead reduced the pickup noise to that of the diode itself. Therefore 15 cm of coax cable was used to extend the diode away from the circuit board. Additionally, the circuit board was raised to a total of 15 cm off the lab bench and not enclosed in any metallic box.

Figure 15. Noise pickup with varied diode position, no shielding of diode.

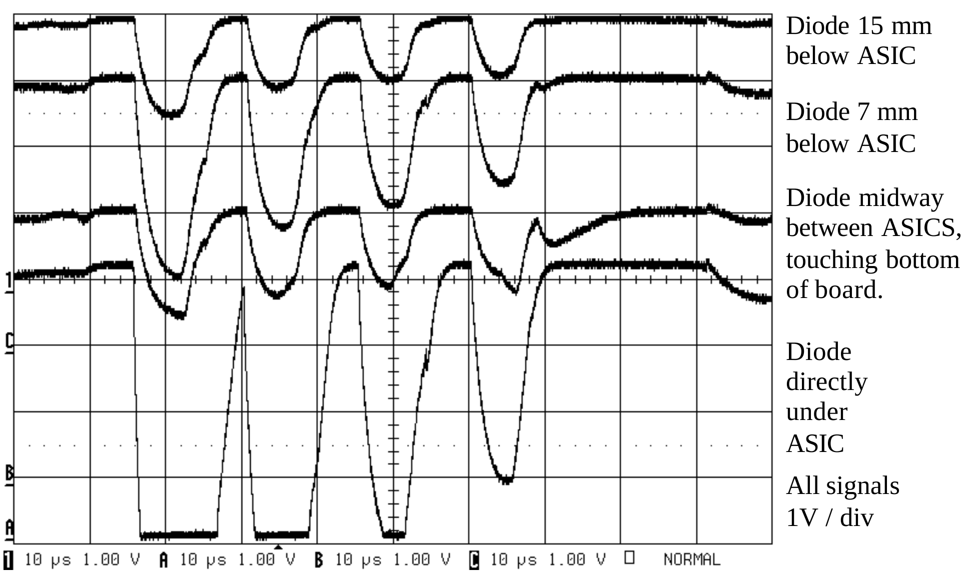


Figure 15 shows that the noise pickup from the address lines is strongest when the diode is directly under the ASIC, and is weakest when the diode is between ASICs. This indicates that the radiation causing the pickup noise is not due to traces within the circuit board running between ASICs. The radiation causing the noise occurs where the circuit traces leave the ground plane to enter the ASIC chip.

Figure 16. Diode noise pickup with position, large grounded foil sheet under PCB.

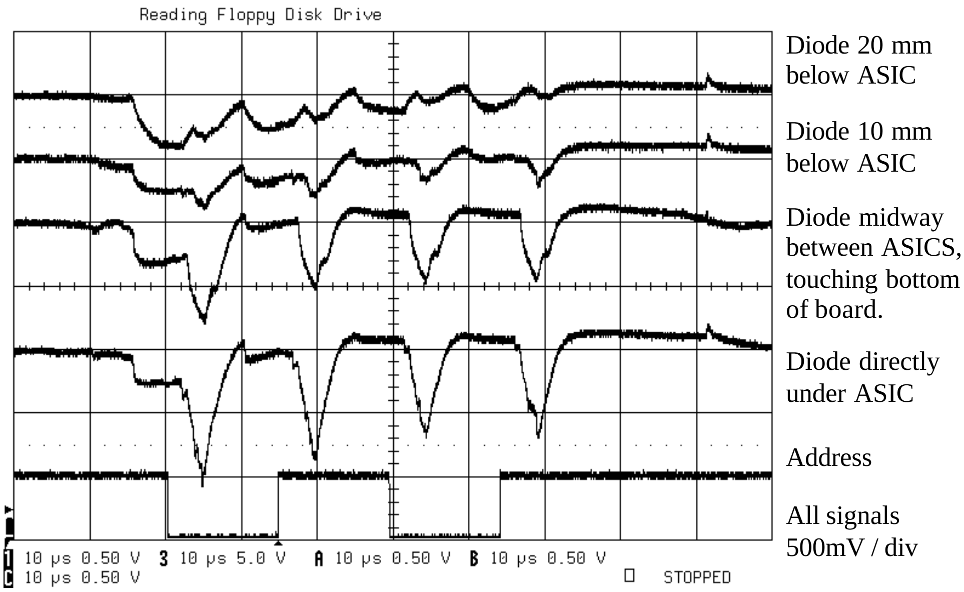
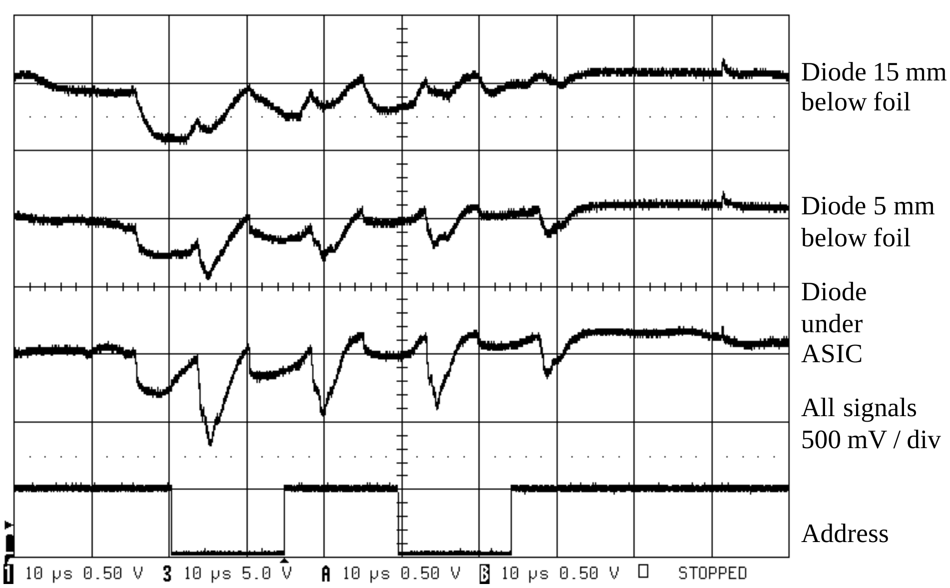


Figure 16 shows that the address switching noise under the ASIC is attenuated by the large foil sheet but the ADC release sample noise is more dominant. A farther distance below the circuit board, the ADC noise is about equal to the address switching noise. One item to note is that the foil sheet is much closer to the ADC chip, separated by a sheet of paper, than to the ASIC chip.

Figure 17. Diode Noise Pickup with position, Foil sheet 3.5 mm Below PCB.



The effect of the proximity of the grounded foil sheet to ADC chips is investigated in Figure 17, where corrugated cardboard of thickness 3.5 mm is used to separate the foil from the ADC chips. The scope plots show that the ADC noise pickup is reduced by half, but the diode is also 3.5 mm farther away from the chip.

Conclusions:

The measurements show the following:

1) Grounded metal foil patch on the diode does not significantly reduce the signal pickup noise.
2) Large grounded metal sheet between the circuit board and the diode significantly reduces the pickup noise.

Due to the address noise being emitted at every ASIC chip, the board is effectively an array antenna of 40 emitters. Due to the large geometry of the circuit board and the close proximity of the small detectors, a flat plate of size equal to the detector is not an effective shield.

Additional items learned in the testing:

1) Increasing diode lead length increases signal pickup unless fully shielded coaxial cable is used, although the higher capacitance of the coaxial cable will increase the front-end white noise.

Theories:

1) Radiation is produced at the point where the circuit board trace leaves the ground plane to make a chip connection.
2) The radiation in the near field has magnetic components which cannot be blocked by copper or aluminum conductors.
3) Following from 2, the foil sheet reduces coupling better when it is some distance away from the emitter, out of the close-in near field.

Suggestions for Designing GLAST Calorimeter:

1) Have all integrated circuits and connectors on the top side of the circuit board. This may not be realizable, as with the prototype board, the ADC chip was put on the circuit board backside due to space limitations.
2) Have another grounded metallic sheet between the circuit board and the PIN diode.
3) Metallic foil does not need to be applied to the PIN diode package.
4) Diode lead length should be minimized. Coaxial lead should be used if diode leads have lengths greater than 3 cm.